Inclusion of Hermetia illucens larvae meal on rainbow trout (Oncorhynchus mykiss) feed: effect on sensory profile according to static and dynamic evaluations

Inclusion of *Hermetia illucens* larvae meal on rainbow trout (*Oncorhynchus mykiss*) feed: effect on sensory profile according to static and dynamic evaluations

RUNNING TITLE Sensory profile of rainbow trout fed insect meal

Monica Borgogno[a], Caterina Dinnella[b], Valeria Iaconisi[a], Renzo Fusi[b], Claudia Scarpaleggia[a], Achille Schiavone[c], Erminio Monteleone[b], Laura Gasco[d], Giuliana Parisi[a]*

[a]Department of Agri-Food Production and Environmental Sciences (DISPAA), University of Florence, via delle Cascine 5, 50144 Firenze, Italy

[b]Department of Agricultural, Food and Forest Systems Management (GESAAF), University of Florence, Via Donizetti 6, 50144 Firenze, Italy

[c]Department of Veterinary Medicine, University of Turin, 10095 Grugliasco, Turin, Italy

[d]Department of Agricultural, Forest and Food Science, University of Turin, 10095 Grugliasco, Turin, Italy

* All correspondence should be addressed to:
Giuliana Parisi
Department of Agri-Food Production and Environmental Sciences, Section of Animal Sciences, University of Florence,
via delle Cascine 5, 50144, Florence, Italy
Email: giuliana.parisi@unifi.it

ABSTRACT

BACKGROUND: Diet implementation with insect meal arouses increased attention in aquaculture considering the advantages of this new protein source. The effect of *Hermetia illucens* meal (HI) inclusion in diets on rainbow trout physical-chemical and sensory properties was evaluated. Three diets were prepared: HI0, HI25, HI50, with 0, 25 and 50% of HI replacing fish meal, respectively. Fillet sensory profiles were described by descriptive analysis (DA) and Temporal Dominance of Sensation (TDS) methods. Cooking Loss, WB-Shear Force, proximate analysis, fatty acid composition were also determined.

RESULTS: Diets significantly affected fillets sensory profile. DA indicated significant changes in perceived intensity of aroma, flavour and texture descriptors as a function of diet composition. TDS evaluations provided information on dominance and evolution of sensations perceived in fillets from different diets. The first sensations perceived as dominant were related to texture attributes, followed by flavours. Dominance of fibrousnesses decreased with the increasing of HI in diet. Boiled fish, algae flavours and umami taste clearly dominated the HI0 dynamic profile. The onset of metallic flavour dominance characterized HI25 and HI50. No differences in physical parameters were detected. Principal component analysis highlighted the relationship between sensory attributes and physico-chemical parameters.

CONCLUSION: Sensory description of fillets indicated that HI inclusion induces significant differences in the perceived profile.

Key words

Hermetia illucens, insect feeding, rainbow trout, Descriptive Analysis, Temporal Dominance of Sensation.

INTRODUCTION

The rising demand and consumption for aquaculture feeds have generated a rapid decline in the availability of fish meal (FM) and a concurrent price increase.[1] FM is the optimal animal protein source used in commercial fish feeds.[2] However, the use of FM is both environmentally and economically unsustainable.[1] Alternative protein sources have been investigated to replace FM in livestock feeds, especially in aquaculture. Nowadays, insects are being considered as a novel protein source both for humans and livestock.[3-5] Insects grow and reproduce easily, have high feed conversion efficiency, can be grown on low quality organic waste, do not compete with humans and other farmed animals for nutrients and are particularly suitable for many freshwater and marine fish feeding as a part of their natural diet.[6] Moreover, they are a rich source of protein, lipids, minerals and vitamins.[7] Different insect species have been considered for their possible use in fish feeds and some studies have been carried out.[8-10] Among the different species, *Hermetia illucens* seems to be very interesting as sustainable alternative to replace FM in aquaculture feeds.[8] *H. illucens*, is suitable to be reared on organic wastes by converting them into protein-rich and lipid-rich biomass, therefore it can be used for various purposes including animal feeding, biodiesel and chitin production.[6]

Changes in fish diet affect fish flesh sensory characteristics[11,12] such as texture[13,14] and volatile compounds.[15,16] Previous studies showed that the replacement of FM with insect protein in aqua feeds determines changes of chemical composition of fish muscle, especially for lipid content and fatty acid profile.[17,18] In several studies relationships were found between fish flavour, muscle chemical composition[19] and fatty acid profiles.[20-22] Considering the growing interest of *H. illucens* as alternative protein

source to replace FM in the fish feeds, it can be highlighted that until now the studies on the related effects on sensory properties of fish meat are scarce.[17,18,23]

Modifying feeding practice without taking into account possible changes in fish sensory properties appears a risky option[24], since modifications on fish flavour and aroma can affect the perceived quality[25] and the acceptability by consumers.[16]

Descriptive Analysis (DA) and Temporal Dominance of Sensations (TDS) have been found as methods providing complementary information to describe food sensory properties.[26] DA permits identification, quantification, and description of food sensory attributes.[27] It is useful when a detailed description of the sensory properties is desired and provides a picture of the perceived differences among products in terms of intensity of sensory attributes.

TDS tracks the evolution of "dominant" sensations (the ones catching the attention) during the product evaluation.[28] The dynamic of perception has important consequences for a better understanding of the processes used by consumers to assess acceptability and sensory properties of food products.[29]

In this work, DA and TDS were utilised to investigate the effect of replacing part of diet proteins with *H. illucens* on sensory properties of rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792). The physical-chemical characteristics and sensory properties of rainbow trout fed regular diet with FM as exclusive source of protein or fed diet including *H. illucens* in partial replacement of FM were described and compared. Moreover, the relationships between physico-chemical characteristics and sensory profile of fillet samples were investigated.

MATERIALS AND METHODS

Sample characteristics

100 Diet formulation

101 Three isoproteic and isolipidic diets were formulated (Table 1), in which
102 *Hermetia illucens* prepupae meal (HI; Hermetia Deutschland GmbH & Co. KG
103 (HDKG), Baruth/Mark, Germany) substituted 0% (HI0), 25% (HI25) and 50% (HI50)
104 of FM

105

106 Fish feeding and sampling

107 The experimental trial was performed at the experimental facility of the
108 Department of Agricultural, Forest, and Food Sciences (Italy). A total of 360 rainbow
109 trout (*Oncorhynchus mykiss*), with an average initial weight of 178.9 ± 9.81 g, was
110 individually weighed and randomly distributed in twelve fiberglass tanks (1 m^3; T:
111 13±1°C; dissolved oxygen: 7.6 - 8.7 mg L^{-1}; water flow: 8 L min^{-1}), in an indoor
112 openwater system (30 fish per tank). Experimental diets were randomly assigned to the
113 tanks.

114 Fish were fed by hand twice a day at 1.5% of body weight, and fish were
115 weighted in bulk every 15 days to adjust the feeding rate.

116 At the end of the trial (92 days), fish were individually weighed and 30 fish for
117 each diet were slaughtered, accurately packaged inside polystyrene boxes with ice
118 covering, and brought to the Department of Agri-Food Production and Environmental
119 Sciences (Florence, Italy). After the arrival, all the fish were weighed, dissected and
120 filleted; the fillets were vacuum packaged, and frozen at −80°C until analyses.

121

122 Sample selection and preparation for sensory evaluations

123 Fish were ranked within each diet according to their weight. Individuals with the
124 highest weights within the diets and with comparable weights across diets were selected
125 for sensory evaluations (Table 2). In total, 15 individuals were selected from each diet,

four were utilised for Descriptive Analysis (DA) and three were utilised for Temporal Dominance of Sensation (TDS) analysis. The remaining individuals were used to set up the evaluation conditions and for sensory panel training purpose.

Before evaluations, fillets were thawed at 4°C for 24 h, washed and accurately dried with paper, and skinned. The part close to tail was discharged and the ventral fish bones removed. Samples were prepared by cutting the cleaned fillets in several portions of 4±0.2 g each, and around 22 portions from each individual were obtained. Each portion was wrapped in an aluminium foil, and stored at 6-8°C until the evaluation session started.

Wrapped samples were steam cooked for approximately 1.30 min, until reaching a temperature of 62°C at the heart and immediately presented to subjects for evaluation.

General sensory evaluation conditions

Samples were presented monadically and identified by a three-digit code. The presentation order was randomized between subjects and sessions. The order of attributes was balanced between subjects to minimize a possible ‘‘proximity’’ effect and was always the same for a given assessor. After each sample, subjects rinsed their mouth with water for 30 s, had some plain crackers for 30 s and finally rinsed their mouth with water for a further 30 s. Subjects took a fifteen min break after every session. Data were collected with the software Fizz (ver. 2.47.B, Biosystemes, Couternon, France).

Subjects of the sensory evaluation

Ten subjects, 8 males and 2 females, aged from 20 to 30 years, regular fish consumers, were recruited. The subjects were informed that the aim of the evaluation was the description of sensory properties of fish fed diets containing also proteins from

152 insects. Before starting with the experiment, a written informed consent was obtained
153 from each subject. The subjects had no history of disorders in oral perception.
154
155 Sensory evaluation by Descriptive Analysis
156 Training sessions: sensory vocabulary development and subject training
157 Panellists participated in three training sessions of about 60 min each. The
158 subjects developed a vocabulary describing differences and similarities between
159 experimental samples in two different sessions, according to a simplified version of the
160 repertory grid method.[30] The initial list of attributes was reduced to achieve a list that
161 comprehensively and accurately described the product space: redundant and/or less-
162 cited terms were grouped on a semantic basis and/or eliminated according to the
163 subjects' consensual decisions. A main list of attributes was developed (Table 3) which
164 described the texture, taste and flavour of fish samples. Some standards were prepared,
165 as reported in Table 4, to induce a weak/moderate intensity. A nine point category scale
166 labelled at the extremes with ''extremely weak'' (corresponding to 1) and ''extremely
167 strong'' (corresponding to 9) was utilised for evaluation. Two repetitions of the whole
168 set of samples were performed in individual booths. Assessor and panel performance
169 were validated by evaluating two sets of samples used for the study. Panel and assessors
170 data were analysed using Panel Check software (ver. 1.4.0, Nofima, Trømso, Norway).
171
172 Evaluation
173 The evaluation of fish meat from each diet was replicated four times in four
174 sessions. In each session, each panellist evaluated three individuals, one from each diet.
175 Two samples from each individual were tested. The first sample was utilised for aroma
176 (ortho-nasal odour) and texture assessment, while the second sample was utilised for

177 taste and flavour evaluation. The overall aroma and flavour descriptors were always
178 presented as the last attribute of the relevant list.
179
180 Sensory evaluation by Temporal Dominance of Sensations
181 Subjects participated in three training sessions. In the first session, the concepts
182 of dominance and temporal evolution of sensations were explained to the subjects.
183 Then, the most relevant attributes for describing the temporal evolution of sensory
184 properties were selected from the attribute lists used for DA. Nine attributes were
185 selected: Melt in mouth, Tenderness, Juiciness, Fibrousness, Metallic, Boiled fish and
186 Algae flavours, Umami, and Astringency. Two sessions were performed for training
187 subjects with the use of the computer system for TDS data acquisition. Panellists were
188 trained to click on the ‘‘Start’’ button as soon as the sample was in the mouth and to
189 immediately start the evaluation. Performance of panellists and eventual artefacts were
190 evaluated by visual inspection of individual out-put of training session evaluations.
191 Panellists participated in six evaluation sessions. Two sessions per day were
192 performed and three individuals, one from each diet, were evaluated twice in the same
193 day, in two independent sessions. In total, three individuals per each diet were
194 evaluated. The total evaluation time was 90 sec.
195 Sample presentation and evaluation conditions were the same described for DA
196 evaluations.
197
198 Physical analyses
199 A number of 4 fish for each diet was randomly weighed and slaughtered.
200 Analyses on physical and chemical properties were performed on the cooked fillets of
201 each sample. The cooking loss (CL) was calculated by measuring the difference in
202 weight of the fillet before the cooking process and after, according to the formula:

203 $100 \times$ [raw fillet weight - cooked fillet weight (g) / raw fillet weight (g)]

204

205 Texture analyses were carried out using a Zwick Roell® 109 texturometer (Ulm,
206 Germany) with the Text Expert II software, equipped with a 1 kN load cell. The
207 Warner-Bratzler shear force test (WB-SF) was performed on the cranial part of the fillet
208 epaxial region (two measurement for each fillet). A straight blade (width of 7 cm),
209 perpendicular to muscle fibre direction, was utilised at a crosshead speed of 30 mm/min
210 to 50% of total deformation. Maximum shear force, defined as maximum resistance of
211 the sample to shearing[31] was determined from the plot of force (N) compared with
212 deformation (%) and expressed as mean.

213

214 Chemical analyses

215 Proximate composition of HI meal, experimental diets and cooked freeze-dried
216 fillets from the three groups of fish differently fed was determined according to AOAC
217 procedures.[32] Dry matter, ash, crude protein and ether extract were determined
218 according to 950.46, 920.153, 976.05, and 991.36 methods, respectively.

219 The fatty acid (FA) group composition was analysed on total lipid extract[33] of HI
220 meal, experimental diets samples and cooked muscle samples obtained from fish fed
221 different diets. The FAs composition was determined by gas chromatography (Varian
222 GC 430; Agilent, Palo Alto, CA, USA) equipped with a flame ionization detector and a
223 Supelco Omegawax™ 320 capillary column (30 m $\times$ 0.32 mm i.d., 0.25 μm film and
224 polyethylene glycol bonded phase; Supelco, Bellefonte, PA, USA). FAs were identified
225 by comparing the FAME retention time with the standard Supelco 37 component
226 FAME mix (Supelco). Individual FAs were quantified using tricosanoic acid (C23:0)
227 (Supelco) as internal standard. FAs were expressed as a percentage of total FAME.

228

229 Statistical analysis

230 Intensity data from the trained panel were analysed by multi-block PCA
231 (Tucker-1) and by *P**MSE plot (Panel Check software, ver. 1.4.0, Nofima, Norway) to
232 assess panel calibration and assessor performance, respectively.[34] Based on the *P**MSE
233 plots and Tucker-1 plot, 2 out of 10 subjects were considered unreliable and were taken
234 out from further data analysis.

235 Principal Component Analysis (PCA) was carried using the mean data for each
236 repetition, in order to geometrically represent the variability associated to diets and
237 individuals by using The UnscramblerX 10.3 software (Norway). Samples were
238 included as dummy variables (downweighted in the data matrix) to improve the visual
239 interpretation.[35] The full cross validation was computed to validate the interpretation of
240 the first two components.

241 Every sensory attribute was analysed following a two-way factorial design in
242 which the diets and panellist were treated as a fixed effect and as a random variable,
243 respectively.

244 The mean dominance curves for each treatments and six repetitions were
245 computed from raw software coding (1 selected; 0 not selected). The data of TDS were
246 analysed by the software Fizz (ver. 2.47.B, Biosystèmes, Couternon, France). When the
247 TDS curves were plotted, two additional lines were drawn for the chance and significance
248 levels. The chance level refers to the dominance rate that an attribute could obtain by
249 chance. Its value is inversely proportional to the number of attributes (P_0=1/p, where p is
250 the number of attributes). The significance level (*Ps*) is the minimum value this
251 proportion should be equal if it is to be considered significantly ($p<0.05$) higher than P_0.
252 Rosner[36] recommended that $np(1-p)>5$ (where n=number of trials and p=probability of
253 success). In the present study, 10 panellists performed six replications of each product and
254 nine attributes were utilised, thus the number of observation was satisfied ($np= 5.87$).

Normality of data distributions was tested by the Kolmogorov-Smirnov test on cooking loss, WB-shear force, proximate analysis and fatty acid composition. One-way ANOVA was performed on physical-chemical results, considering the diets as main effect. The Bonferroni post-hoc test was applied to check the significance of the differences among diets, using SPSS version 17.0 software (SPSS Inc. Illinois, USA).

A PCA was calculated after standardization of variables in order to assess the relationship among the sensory, physical and chemical dataset, using The UnscramblerX 10.3 software (Norway).

RESULTS

Descriptive analysis

The analysis of principal components (PCA) was performed using all tested individual as independent samples, in order to evaluate the differences due to both the different diets and those relevant to biological variability among of individuals reared following the same diet. The PCA correlation loading plot (Figure 1) showed that samples were mainly discriminated along the first component (PC1: 42% explained variance) according to the diets. Fish fed with the control diet were positioned on the left side of the map, while those with 50% of HI meal were located on the right. The HI25 samples were located closed to the origin of the component. Along the second component (18% of explained variance), sample position reflects the sensory variability due to the biological variability of individuals within the same diet. Considering the distribution of samples in the perceptual space, it appears that the differences among samples due to different diets are more evident than those perceived between different individuals fed the same diet. Thus, the individual evaluations belonging to the same diet were treated as repetition.

The mixed ANOVA model on the intensity data of the sensory attributes were performed, in order to estimate the sample effect (three levels: HI0, HI25, HI50) (Table 5). A significant sample effect of the diets was found for 12 out of 19 attributes evaluated. No significant effects of assessor × product interactions were found for the significant attributes (data not reported). Results reported in Table 5 showed that the main differences were found between the control (HI0) and HI50 samples, while HI25 expressed some similarities with HI0 for some attributes and with HI50 for the others. Considering the aroma-related attributes, the perceived intensities of boiled fish, algae and overall aroma were significantly higher in HI0 than HI50 samples ($p < 0.001$). On the other hand, the fresh fish aroma showed a significantly higher intensity in HI25 than HI0 and HI50 ($p < 0.05$). Metallic aroma was higher in samples from FM partially replaced with insect proteins diets. Texture attributes resulted significantly more intense in HI50 than HI0 and HI25 ($p < 0.05$). Indeed, samples obtained by fish fed the 50% of insect meal inclusion diet were juicier, more tender and melting more in mouth than HI0 samples. Overall aroma intensity tended to significantly decrease with the increasing of insect protein inclusion.

Boiled fish flavour and sweet taste were perceived as more intense in HI0 samples, with respect to individuals fed insect meal diets ($p < 0.05$). The addition of *Hermetia illucens* prepupae meal also induced a significant increase in overall flavour intensity, independently from HI concentration. Moreover, metallic flavour intensity increased with the increase of HI meal content in the diets.

Temporal Dominance of Sensations

Mean TDS curves of the samples from the three diets are reported in Figures 2–4 for HI0, HI25 and HI50 groups, respectively. In general, the curves showed that the texture attributes dominated the first part of evaluation (0 to 15 seconds), followed by

306 flavour and taste attributes. In HI0 samples (Figure 1) tenderness and fibrousnesses
307 clearly dominated the first part of evaluation. On the other hand, only tenderness clearly
308 dominates the dynamic profile of HI25 (Figure 3) and HI50 samples (Figure 4).
309 Furthermore, it appears that the dominance of juiciness is mainly related to FM partial
310 replacement with insect proteins. Flavour of HI0 samples was dominated by boiled fish
311 and algae flavours even at a lower extent, umami taste was the sensations mostly
312 dominating the after taste. In samples HI25, boiled fish clearly dominated the profile
313 together with algae, metallic flavours and umami. The dynamic profile of HI50 appears
314 complex with several descriptors perceived as dominant at the same time (boiled fish,
315 algae, metallic, umami). Even though umami resulted as the most important attribute in
316 the aftertaste of all samples however some differences among diets have been observed.
317 Indeed, while in HI0 the umami was the only dominant attribute, in HI25 the metallic
318 flavour was dominant and in HI50 the boiled fish flavour persisted until the end of
319 evaluation.
320
321 Physical and chemical characterization of fish fed different diets
322 Table 6 reports results of physical and chemical parameter analyses. No
323 significant effect of diets was observed for both cooking loss and WB shear force,
324 indicating that, from an instrumental standpoint, the samples lose the same amount of
325 water during cooking and were equally soft. Proximate composition of cooked samples
326 was not significantly affected by diets of fish ($p>0.05$). On the contrary, the sum of the
327 principal groups of the fatty acids showed differences associated with the experimental
328 diets. It is of note that HI50 fish have the significantly highest level of saturated fatty
329 acids (SFA), followed by HI25. The HI0 had the significantly lowest content of SFA
330 and the significantly highest content of PUFAω3, showing an inverse relationship with

fish fed *Hermetia illucens* inclusion diets. MUFA and PUFA showed a similar trend, significantly decreasing with the increase of HI meal concentration in diets.

Relationship between instrumental and sensory analyses

The correlation loadings plot in Figure 5 summarizes the main trend of sensory, chemical and physical variables of the samples obtained from fish fed different diets, highlighting the relationship between sensory and instrumental parameters. The explained variance after the first two components (PC) account of 53%. PC1 (37% of explained variance) separated samples without *Hermetia illucens* inclusion in diet from samples fed including HI prepupae meal. PC2 seemed to further separate samples that have different content of HI. The predominant differences between the samples were due to the fatty acids (FAs), mainly SFA that were negatively related to PUFAs. SFA resulted positively correlated to metallic aroma/flavour, overall flavour and tenderness (negative part of PC1), as well as protein and ash content. The positive part of PC1 showed the relationship between PUFA, PUFAω3, MUFA and boiled fish flavour and overall aroma. PUFAω6 seemed highly related to algae flavour, loaded on the positive part of the second component. At the same time, juiciness and melt in mouth attributes were strongly related to PUFAω6 and moisture content. WB-shear force did not play a relevant role in this PCA, as expected considering the lacking of significant differences detected with analysis of variance.

DISCUSSION

Sensory evaluation

Terms freely generated by assessors to describe fish sensory properties are not associated to negative hedonic valence, thus indicating that FM partial replacement with

insect meal did not induce the perception of sensory defects or off-flavours. According to sensory results, differences among diets have been observed. DA showed significant differences in terms of aroma, flavour and texture. These results disagree with previous findings reported in literature. For example, no sensory significant differences have been found with inclusion of insect meal in diets on Atlantic salmon.[18] Performing a triangle test on rainbow trout fed diet with different content of insect meal, Sealey et al.[17] did not find any significant differences. In these studies, differences in FA composition were detected, and the lacking of significant differences in sensory proprieties was quite unexpected since differences in FA composition affect the sensory profile.[20,21] Possibly these results reflect the lack of power of the adopted sensory techniques. The results of the present work further confirm DA as a powerful sensory descriptive technique, providing the accurate description of sample sensory properties.

The dynamic analysis of sensory proprieties confirmed the differences between the groups of fish fed different diets. TDS results partially confirmed the results obtained by DA, and allowed a better understanding of the perception of sensory proprieties during all the chewy process. Fibrousnesses intensity was not significantly different amongst trout samples but this sensation appears to be much more important in HI0 than in HI25 and HI50 samples. The inclusion of HI prepupae meal in diets led to the perception of a more complex sensory profile with several flavour sensations dominating the perception at the same time. Dominance of metallic flavour characterized HI25 and HI50 samples in respect to HI0. This sensation can be seen as unfamiliar or as unexpected in fish thus catching the assessor attention despite its moderate intensity value. Dominance values indicated that the importance of a sensation during food consumption is not necessarily the same as that indicated by intensity ratings from static sensory profiles.[37] Thus, the use of the TDS method for the sensory

characterization of fish samples provides information which complements those from DA studies.

Physical and chemical characteristics and relationship with sensory profile

The partial replacement of FM with HI meal in diets for fish feeding, as alternative source, seems to have effects on qualitative aspects of fillet, in terms of sensory and physico-chemical characteristics.[16,17,23] In the present study, the instrumental physical differences concerning the parameters investigated were not identified. The *H. illucens* meal is a high-value feed source, rich in protein and fat. The fat amount of black soldier fly larvae is extremely variable and depends on the feeding substrate and development stage of the insect. Further, their FA composition depends on the FA composition of the diet utilised for larvae rearing.[3] The lipid content of HI affected the chemical composition of fish fillet, when the FM was partially replaced by the insect meal. In this study, it seems that the inclusion of HI in diets implies a change in FA profile of fish fillet, especially increasing the incidence of SFAs. On the other hand, the PUFA incidences diminish when HI inclusion increases compared to control samples. This trend was also observed in previous studies on Atlantic salmon[18] and rainbow trout,[17] where the amount of whole-body SFAs increased employing diets containing increased amount of HI. Regarding proximate composition, in our trial no significant differences in fillets from different groups of fish were noted. Contrariwise, Sealey et al. observed that fillet moisture and lipid composition were significantly altered by replacement of dietary FM with black soldier fly prepupae meal in rainbow trout.[17] They reported that fish fed diets containing HI had significantly greater moisture and lower lipid in muscle in comparison with fish fed the control diet. Even though these analyses were conducted on raw muscle, while in our study the analysis was performed on cooked fillets, the results of this work are partly in line with these

previous findings, since a trend for a lower lipid content in fillet with increasing inclusion of insect meals, even if not significant, was also observed.

Relationship between sensory and instrumental analyses

The compositional differences of the diets, i.e. lipid content, FA profile and proximate composition, can have affected the sensory properties. These variations in diet modify, in particular, lipid content and composition of fish muscle. Overall aroma and flavour intensity are both dependent on final product lipid content.[12] This study has highlighted the relationship between sensory and physico-chemical parameters (Figure 5). FAs, flavour and texture attributes showed the main relationships. SFA increase in the fish fillet with the increased inclusion of HI in the diets, and it seems to be correlated to flavour and texture in fish flesh, in agreement with previous study.[15] The rise of fatty acids had an effect on tenderness of fish meat as confirmed also by Grigorakis et al.[11] and Rincón et al.[12] findings. Valente et al.[38] found a significant relationship between lipid content and both fatty flavour and perception of fatty texture. Additionally, lipid content and FA profile of fillets have a connection to flesh texture[39] and they affect texture attributes, mainly juiciness and tenderness.[11] However, this relationship with tenderness measured with Warner-Bratzler shear force was not revealed in the case of this trial samples. Water contents contributed to juiciness and melting in mouth of the fish samples, in agreement with a previous work findings.[12] Concerning the flavour modification, Grigorakis et al.[11] showed that fat content strongly affects the mouth impression and volatile compounds that were also correlated to differences in sensory taste.

CONCLUSION

Sensory description of fish samples indicated that HI inclusion induces significant differences in the perceived profile. Furthermore, HI inclusion in the diet did not induce the perception of sensations relevant to defects or off-flavours. The effect of diets was highlighted both by DA and TDS descriptions and the information obtained appear complementary. The strict relationship between sensory profile and fatty acid composition was also confirmed by the results obtained. Further study will be necessary to understand if the highlighted differences in sensory properties of fish fed diets characterized by different protein sources would be reflected in liking judgements by consumers.

ACKNOWLEDGMENTS

The research was funded by University of Florence, Ateneo Research Project (2014) and by University of Turin, ex-60% grant (2014).

REFERENCES

1 FAO, *The State of World Fisheries and Aquaculture. Opportunities and Challenges*, FAO, Rome, pp. 3. (2014).

2 Tacon AGJ, Hasan MR and Metian M, Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects, in *FAO Fisheries and Aquaculture Technical Paper* No. 564, Rome pp. 87 (2011).

3 Makkar HP, Tran G, Heuzé V and Ankers P, State-of-the-art on use of insects as animal feed. *Anim Feed Sci Tech* **197**:1-33 (2014).

4 Veldkamp T. & Bosch G., Insects: a protein-rich feed ingredient in pig and poultry diets. *Anim Fron* **5**:45-50 (2015).

5 Bovera F, Loponte R, Marono S, Piccolo G, Parisi G, Iaconisi V, Gasco L and Nizza A, Use of *Tenebrio molitor* larvae meal as protein source in broiler diet: effect on growth performance, nutrient digestibility, carcass and meat traits. *J Anim Sci* **94**:639-647 (2016).

6 van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G and Vantomme P, Edible insects – Future prospects for food and feed security. *FAO Forestry Paper* No. 171, Rome pp. 201 (2013).

7 van Huis A, Potential of insects as food and feed in assuring food security. *Annu Rev Entomol* **58**:563-583(2013).

8 Henry M, Gasco L, Piccolo G and Fountoulaki E, Review on the use of insects in the diet of farmed fish: Past and future. *Anim Feed Sci Tech* **203**:1-22 (2015).

9 Roncarati A, Gasco L, Parisi G and Terova G, Growth performance of common catfish (*Ameiurus melas* Raf.) fingerlings fed *Tenebrio molitor* meal diet. *Journal of Insects as Food and Feed* **1:**233-240 (2015).

10 Gasco L, Henry M, Piccolo G, Marono S, Gai F, Renna M, Lussiana C, Antonopoulou E, Mola P, Chatzifotis S, *Tenebrio molitor* meal in diets for European sea bass (*Dicentrarchus labrax* L.) juveniles: growth performance, whole body composition and in vivo apparent digestibility. *Anim Feed Sci Technol* **220**:34-45 (2016).

11 Grigorakis K, Taylor KDA and Alexis MN, Organoleptic and volatile aroma compounds comparison of wild and cultured gilthead sea bream (*Sparus aurata*): sensory differences and possible chemical basis. *Aquaculture* **225**:109-119 (2003).

12 Rincón L, Castro PL, Álvarez B, Hernández M, Álvarez A, Claret A, Guerrero L and Ginés R, Differences in proximal and fatty acid profiles, sensory

characteristics, texture, colour and muscle cellularity between wild and farmed blackspot seabream (*Pagellus bogaraveo*). *Aquaculture* **451**:195-204 (2016).

13 Olsson GB, Olsen RL, Carlehög M and Ofstad R, Seasonal variations in chemical and sensory characteristics of farmed and wild Atlantic halibut (*Hippoglossus hippoglossus*). *Aquaculture* **217**:191-205 (2003).

14 Sveinsdóttir K, Martinsdóttir E, Green-Petersen D, Hyldig G, Schelvis R and Delahunty C, Sensory characteristics of different cod products related to consumer preferences and attitudes. *Food Qual Prefer* **20**:120-132 (2009).

15 Turchini GM, Mentasti T, Caprino F, Panseri S, Moretti VM and Valfré F, Effects of dietary lipid sources on flavour volatile compounds of brown trout (*Salmo trutta* L.) fillet. *J Appl Ichthyol* **20**:71-75 (2004).

16 Turchini GM, Torstensen BE and Ng W-K, Fish oil replacement in finfish nutrition. *Rev Aquacult* **1**:10-57 (2009).

17 Sealey WM, Gaylord TG, Barrows FT, Tomberlin JK, McGuire MA, Ross C and St-Hilaire S, Sensory analysis of rainbow trout, *Oncorhynchus mykiss*, fed enriched black soldier fly prepupae, *Hermetia illucens*. *J World Aquacult Soc* **42**:34-45 (2011).

18 Lock ER, Arsiwalla T and Waagbø R, Insect larvae meal as an alternative source of nutrients in the diet of Atlantic salmon (*Salmo salar*) postsmolt. *Aquacult Nutr*. doi:10.1111/anu.12343 (2015).

19 Grigorakis K, Compositional and organoleptic quality of farmed and wild gilthead sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) and factors affecting it: a review. *Aquaculture* **272**:55-75 (2007).

20 Izquierdo MS, Montero D, Robaina L, Caballero MJ, Rosenlund G and Ginés R, Alterations in fillet fatty acid profile and flesh quality in gilthead sea bream

(*Sparus aurata*) fed vegetable oils for a long term period. Recovery of fatty acid profiles by fish oil feeding. *Aquaculture* **250**:431-444 (2005).

21 Montero D, Robaina L, Caballero MJ, Ginés R and Izquierdo MS, Growth, feed utilization and flesh quality of European sea bass (*Dicentrarchus labrax*) fed diets containing vegetable oils: a time-course study on the effect of a re-feeding period with 100% fish oil diet. *Aquaculture* **248**:121-134 (2005).

22 de Francesco M, Parisi G, Pérez-Sánchez J, Gómez-Réqueni P, Médale F, Kaushik SJ, Mecatti M and Poli BM, Effect of high level fish meal replacement by plant proteins in gilthead sea bream (*Sparus aurata*) on growth and body/fillets quality traits. *Aquacult Nutr* **13**:361-372 (2007).

23 St-Hilaire S, Sheppard C, Tomberlin JK, Irving S, Newton L, McGuire MA, Mosley EE, Hardy RW and Sealey W, Fly prepupae as a feedstuff for rainbow trout, *Oncorhynchus mykiss*. *J World Aquacult Soc* **38**:59-67 (2007).

24 Verbeke W, Functional foods: Consumer willingness to compromise on taste for health? *Food Qual Prefer* **17**:126–131 (2006).

25 Amberg S and Hall T, Communicating risks and benefits of aquaculture: a content analysis of U.S. newsprint representations of farmed salmon. *J World Aquacult Soc* **39**:143-157 (2008).

26 Dinnella C, Masi C, Naes T and Monteleone E, A new approach in TDS data analysis: A case study on sweetened coffee. *Food Qual Prefer* **30**:33-46 (2013).

27 Lawless HT and Heymann H, *Sensory evaluation of foods: Principles and practices*. In Chapman & Hall (Eds.), New York, USA: Springer (1998).

28 Pineau N, Schlich P, Issanchou S, Imbert A, Cordelle S, Mathonnière C, Rogeauxe M, Etiévantc P and Kösterf E, Temporal dominance of sensations: Construction of the TDS curves and comparison with time-intensity. *Food Qual Prefer* **20**:450-455 (2009).

29 Piggott JR, Dynamism in flavour science and sensory methodology. *Food Res Int* **33**:191-197 (2000).

30 Piggott JR and Watson MP, A comparison of free-choice profiling and the repertory grid method in the flavor profiling of cider. *J Sens Stud* **7**:133-145 (1992).

31 Veland JO and Torrissen OJ, The texture of Atlantic salmon (*Salmo salar*) muscle as measured instrumentally using TPA and Warner-Bratzler shear test. *J Sci Food Agr* **79**:1737-1746 (1999).

32 AOAC, *Official Methods of Analysis of AOAC International*, 17th Association of Official Analytical Chemists, Gaithersburg. Maryland, USA (2000).

33 Folch J, Lees M and Sloane-Stanley GH, A simple method for the isolation and purification of total lipids from animal tissues. *J Biol Chem* **226**:497-509 (1957).

34 Næs T, Brockhoff P and Tomic O, *Statistics for sensory and consumer science*. John Wiley & Sons (2011).

35 Martens H and Martens M, *Multivariate Analysis of Quality: an Introduction*. New York: John Wiley & Sons Ltd Ed (2001).

36 Rosner B, *Fundamentals of Biostatistics*, 4th ed. by Belmont: Duxbury Press (1995).

37 Dinnella C, Masi C, Zoboli G and Monteleone E, Sensory functionality of extra-virgin olive oil in vegetable foods assessed by Temporal Dominance of Sensations and Descriptive Analysis. *Food Qual Prefer* **26**:141-150 (2012).

38 Valente LMP, Cornet J, Donnay-Moreno C, Gouygou JP, Bergé JP, Bacelar M and Cardinal M, Quality differences of gilthead sea bream from distinct production systems in southern Europe: intensive, integrated, semi-intensive or extensive systems. *Food Control* **2**:708-717 (2011).

39 Johansson L, Kiessling A, Kiessling KH and Berglund L, Effects of altered ration levels on sensory characteristics, lipid content and fatty acid composition of rainbow trout (*Oncorhynchus mykiss*). *Food Qual Prefer* **11**:247-254 (2000).